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A newly developed EMS unit: Some preliminary results demonstrating its efficacy

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ABSTRACT

An electromyostimulation (EMS) unit that provides a range of stimulation variables was developed and used in a preliminary study of the current-torque relationship during percutaneous EMS. The knee extensors of one lower limb of 10 subjects received stimulation on 3 different days. The current torque relationship was studied using an incremental protocol. A two second train of 500 us square monophasic pulses at 60 Hz was used to elicit one contraction every minute. Peak current and peak torque values among subjects ranged from 229 to 344 mA and from 61% to 106% of a given subject's maximum voluntary isometric torque.

The new EMS unit consistently elicits torque during stimulated contractions, therefore providing the basis to evaluate the efficacy of a wide range of stimulation protocols.

INTRODUCTION

During exposure to a microgravity environment, muscles in the lower extremity atrophy. During Skylab II the astronauts demonstrated a 20% loss of strength of their knee and hip extensor muscle groups after only 28 days in orbital flight [4]. One of NASA's objectives is to develop and verify countermeasures to reduce the effects of microgravity on the musculoskeletal system. Conventional exercise for up to 2.5 hours a day during flight does not maintain normal muscle size and strength. The Kennedy Space Center has initiated a research program in which one goal is to determine if transcutaneous electromyostimulation (EMS) might aide in the fight against disuse atrophy while not encroaching upon costly crew time. In a pilot study EMS was applied to 3 subjects during 30 days of 6 degree head down bedrest. Subject tolerance to EMS determined the stimulation level. Unfortunately this level varied greatly amoung subjects. This was due to the difference in individual tolerance to the stimulation.

In order to more effectively test EMS as a countermeasure, subject variation in acceptance cannot limit the stimulation level. By customizing stimulation variables to an individuals preference, the level of effective EMS could be increased for all subjects. To customize EMS to individual preference, a EMS stimulator was designed. This stimulator provides a large adjustment range on all stimulation variables and the ability to create an arbitrary pulse shape stimulus. This paper discusses the basic design of the programmable arbitrary stimulator and the initial data collected using this device.

EQUIPMENT AND METHODS

The programmable arbitrary stimulator is composed of 3 basic components: Compaq computer, Krohn-Hite arbitrary waveform generator, and a customized power amplifier. The computer allows for pulse shape design, for simulation variable selection and for acquisition of current and torque levels. Two arrays are loaded into memory and used to develop two analog signals. The first signal controls the frequency of the pulses and the second modulates pulse amplitude. The length of these signals and the analog output card clock speed control the length of the contraction.

A Krohn-Hite arbitrary waveform generator provides the pulse shape. The pulse shape is a 200 point wave which is designed on the computer, and then downloaded and stored in the arbitrary generator. The frequency signal from the computer is used to trigger the generator to output the pulse shape. This pulse train is sent to the power amplifier.

The pulse train from the generator is amplified using a current amplifier and a step-up transformer, thereby providing sufficient stimuli to activate skeletal muscle. The amplifier also modulates the pulse train amplitude from the computer and outputs this stimulus to the subject. In order to determine the efficacy of different stimulation variables, an initial study was conducted to determine

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a baseline response of muscle to current and to determine the reproducibility of the current-torque relationship elicited with this EMS system. Six male and four female volunteers acted as subjects. One knee extensor from each subject was sensored with two carbon conditioned electrodes. The subject was then securely positioned into an instrumented EMS chair. [2] The protocol consisted of 3 maximum voluntary isometric contractions (MVC) separated by 1 min of rest. These were followed by a series of electrically stimulated contractions. The stimulation variables were set as follows: pulse width-500us, frequency 60 H, contraction time 2 seconds with the first second of the contraction ramped to the amplitude setting. The stimulation amplitude was manually increased in a stepwise manner to subject tolerance. The 2 seconds trains were separated by 1 minute to minimize muscle fatigue. Subjects were tested on 3 different days separated by at least one day after following one or two preliminary exposures to EMS. Electrode placement was marked on the skin and maintained throughout the study. The stimulation level (peak current) and the torque developed for each pulse train were measured and recorded.

RESULTS

Subjects were included in the data analysis if they attained 65% of their MVC during EMS on each day of testing. Two male and one female subject were excluded as they failed to meet this criteria. MVC was determined as the highest single value measured any testing day.

The current and torque were normalized by body weight and MVC, respectively. Figure 1 presents the current-torque relationship of the 7 subjects averaged for each day of testing. These data indicate a very strong correlation between stimulation level (current/wt) and the torque output of the muscle (%MVC). The equation describing the relation between current and torque when data for the 3 day were considered together is (r^2=0.89 $p<0.05$):

$$\%MVC = 0.045 - 0.196x + 0.172x^2 - 0.019x^3$$

where: %MVC is torque output/MVC
x is current level/body weight

The nature of the current-torque relationship demonstrates a threshold effect prior to muscle response, followed by a sensitive area, and finally approaching a saturation level.

DISCUSSION

Having developed an EMS system which will reproduce the current-torque curve on a day to day basis, we can begin to determine which stimulation variables

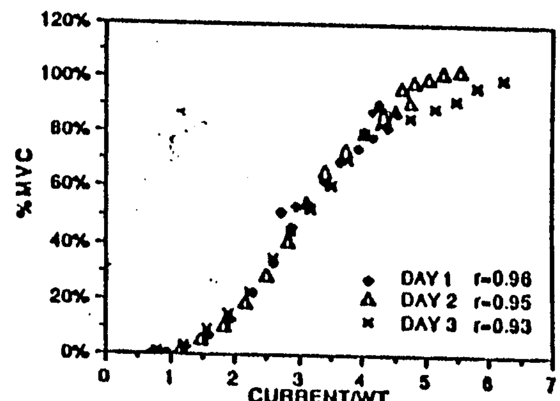

Figure 1: Current-Torque relationship in the Knee Extensors.($p<0.05$)

are most effective at eliciting a higher level contraction while minimizing subject discomfort. A few investigators have reported work in this area[1,3]. For example Hultman et. al. measured force output with increasing pulse width using a square pulse stimulation pattern. Force increased dramatically with increasing pulse width from 0 to 500us and the increased much less for 500us to 1000us [3]. Delitto et. al. compared the subject tolerance to three different pulse shapes. His work indicated that although no specific pulse shape tested proved comfortable to all subjects, subjects did prefer one type of pulse shape and when using that specific pulse shape high force contractions could be elicited [1]. In future work using this stimulator, we will maximize both force output and subject tolerance by customizing stimulation variables and thereby increase the effective level of EMS contractions.

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